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Bacharelado em Design de Moda

Iridescent Glass Surfaces for Jewelry and Wearable Art

One Woman's Process of Creativity

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Iridescent Glass Surfaces for Jewelry and Wearable Art

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Abstract

This research explores creativity through process, within an interdisciplinary practice between art and science. This merging of disciplines stimulated the author to follow a particular path to discovery using physical tools given by the Vicarte research unit, and a mental contemplative space made possible through fluid creation without commercial purpose. In this dynamic scenario, glass as a technically challenging material also favored the development of skills in problem solving, leading to new discoveries.

As a consequence, a new and environmentally friendlier method for creating iridescent surfaces on glass silver mirrors is presented utilizing an electrochemical anodizing process. This process diverges from the traditional methods used to obtain iridescent glasses that were potentially toxic.

The rise of said methodology inspired intense practical research that later led to the creation of conceptually inspired wearable glass pieces. Additionally, the work encompasses beliefs spread by the Contemporary Jewelry Movement, which define a category of objects that are involved with fine art practice and critical thinking. The resulting glass objects, conforming to different areas of the body, were used to challenge the notion of jewelry practice and also questioned the methods with which we learn and think creatively.

Keywords: Iridescence, wearable, glass, design, art, creativity.

Resumo

Neste estudo, o potencial humano para o desenvolvimento da criatividade através de práticas interdisciplinares entre arte e ciência foi discutido. Esta combinação mostrou-se eficiente para a adoção de uma nova metodologia de trabalho enquanto motivações divergentes originadas de ambas as disciplinas me estimularam a seguir um caminho particular para a resolução de problemas. Tal metodologia me levou a novas descobertas, facilitadas pelas ferramentas físicas e o espaço mental contemplativo que foi experimentado durante a vivência na unidade de investigação Vicarte. Eu estive longe do universo do design comercial que costuma guiar as minhas práticas criativas e este novo cenário se provou muito eficaz para a criação de peças não tradicionais.

Por consequência de uma nova forma de pensar, o método eletroquímico de anodização de metais foi aplicado em espelhos de prata afim de criar superfícies iridescentes em peças de vidro. Esta nova abordagem é ecologicamente mais sustentável do que os processos tradicionais utilizados para obter efeitos iridescentes em vidro.

A descoberta deste novo método decorativo estimulou uma intensa prática artística experimental, levando à criação de peças conceitualmente vestíveis em vidro, alinhadas com as crenças disseminadas pelo Movimento de Joalheria Contemporânea. Esta corrente de design de joalheria abraça uma categoria de objetos envolvidos com práticas artísticas e pensamento crítico. Os "vidros vestíveis" por mim criados constituem um autoquestionamento acerca da minha relação com o design ao mesmo tempo em que questiona os métodos vigentes de aprendizado e pensamento criativo.

Palavras - chave: iridescência, vestível, vidro, design, arte, criatividade.

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1. Introduction

This investigation begins with a close look at the nature of iridescent glass surfaces: optical phenomena first revealed in archeological glasses (Navarro, 2003) where corrosion affected the glass surface. The surface deterioration led to the perception of shifting colors which varied according to the viewing angle and such pieces were highly regarded for their aesthetic value. Investigation into manmade iridescent glassware, such as pieces from the late 19th century made by designers like Tiffany and Carder¹ (Freeman, 1956) and also the cheap and popular Carnival Glass² (Thistlewood, 2008) were important for this work, since a research to understand the already known production methods was a point of departure.

Historically, with the exception of natural corrosion over time, iridescent glass was produced by using chemicals like stannous chloride and other metallic salt solutions (Bray, 2001). These methods involved potentially toxic release of fumes. In an opposite side, this work searches for an environmentally friendlier and less toxic process for achieving iridescent surfaces through a dynamic research that goes beyond the glass bibliography. As a result, an innovative and sustainable method to produce iridescent glass films was developed by anodizing silver mirrors deposited on the glass surface.

In the search for the forms that would receive the iridized decoration, wearable glass pieces that conform to different areas of the human body were developed. Inspired by the 20th century contemporary jewelry movement³ (Skinner, 2013), and better contextualized in the next chapter, we will see that my practice grew to include an inquisitive "what if" approach. This involved looking to places on the body where an ornament might not usually be expected, and using that area as the inspiration for developing new forms. This resulted in the development of different ideas as the discovery process itself continually changed the physical forms.

Thus, the heart of this thesis derives from the peculiar mixture of art and science within Vicarte Research Unit and from questions regarding how being immersed in an intersection between the two disciplines boosts creativity. Later, we can trace the results of this inter-disciplinary research and how they encouraged a divergence from a more traditional design methodology. As my prior personal experience as a fashion and jewelry designer followed a fixed method involving a tightly targeted product conception research followed by sketching and modeling, this new way of developing my creativity non-commercially, through art and science, stood out as unique.

¹ Louis Comfort Tiffany and Frederic Carder were amongst the renowned designers and glassmakers who made iridescent glass famous in a wider perspective. Tiffany called his creations "Favrile Glass" while Carder had "Aurene" as the signature for his designs.

² Mould pressed and factory made glassware that was produced for the masses. Its strong iridescence, detailed patterns and the very attractive prices made it popular within the working class.

³ Jewelry practice emerged in the 1940's in which materials and skills are placed in the service of ideas rather than being celebrated as themselves. (Skinner, 2013)

Opposite to the above-mentioned product driven design process, each decision made in the present research responded to the previous results of pure material exploration, such as testing different surfaces on which to apply the iridescence. Diverse conditions of the same experiment with different glass material, in search for unpredicted results favored new discoveries that have actually just begun. Certainly, this simultaneous experimentation must be responsible for these new forms and surfaces.

This work is as much about the final result (discovering a surface technique, new shapes to receive it and the science behind the technique) as it is about the process or the path to arrive at the discovery itself. This research is also an innovative process that can be relevant for preserving the tradition of creating iridescent glass surfaces, which I believe that by its nature, will always be pleasing to the eye.

2. Artistic Drive : Jewelry and Wearable Art

After a thorough bibliographic research, and dare I say internet investigation, I recognized the use of the terms "Contemporary Jewelry" and "Art Jewelry" (Skinner, 2013). Both designations are used to indicate works that are closely related to craft techniques and fine art practices. Always intended to be used on the human body, be they defined as adornment or as conceptual art pieces alone, they belong to a category of objects that can connect to art, jewelry, fashion and prosthetics. Some examples are textile art, conceptual jewelry or sculpture. The following works caught my attention and naturally acted as influences on my practice for the present work:



Figure 2.1: Profile Ornament for Emmy Van Leersum by Gijes Bakker, 1974 (van Zijl, 2005).



Figure 2.2: Piece from the series "Forms of The Body" by jewelry artist Kiwon Wang, 2000 (Wang, 2000).

In order to help the viewer better understand my aesthetic motivations, it is important to notice how the adornment can be used to enhance our perception of a "bodily topography", as exemplified in both works above. In such works, the body's supporting function of being a mere display for jewelry as a symbol of social status is denied and it is elevated to the spotlight where the body itself is the protagonist from an artistic perspective.

Such a conceptual approach opens a potential for critical thinking around jewelry practice and resonates with the beliefs spread through the Contemporary Jewelry Movement. The movement encourages the creation of pieces that involve different ways of wearing, be it related to the physical

aspects or intellectual motivations around jewelry making and the act of wearing jewelry. For social and political questions concerning the inherent preciousness of stones and noble metals, this allows resignifying preciousness as a personal connotation by the inclusion of foreign materials to jewelry making, setting it apart from traditional jewelry as we know it from the common shop windows and magazines. (Skinner, 2013).

To contextualize my artwork, let's look at this statement made by the craft theorist and historian Jorunn Veiteberg, who speaks about the first contemporary jewelry authors back in the 1940's:

"They showed that any material, form or technology could be used in creating jewelry that acquires preciousness from personal association rather than intrinsic value. They explored jewelry as an experience and a performance: wearable art, assemblage, sculpture to wear, the connotations to fine art is strong. To me, that is the main thing with contemporary jewelry, that it associates itself with an avant garde thinking using strategies in art and design that goes beyond the goldsmithing, the metalwork."

(Extract from the lecture "The widespread Liberation of Jewelry" at the Danish Design Museum in Copenhagen. October, 2015.)

Resembling my experience as a jewelry designer, the abovementioned ideas are incorporated in my art practice. Also combining glass and technology now to a curiosity around iridescence on glass, as the research will show, I hope to build a bridge between those fields of interest - art and science, while exploring my creative process throughout the work.

3. The Science Behind the Experimental Process: Fundamentals

I have always been intrigued by objects that show changing colors and among my studies about the history of glass during the master, it was clear that this effect, called iridescence, was largely exploited in glass making. Before elucidating this historic scenario, we must first understand some physical concepts that are fundamental to the comprehension of the iridescence effect.

3.1 Iridescence and Thin Film Interference

Iridescence is popularly known as the "rainbow effect" and the origins of the word attest to the fact that it derives from the greek "iris", meaning "rainbow" (Webster, 2016). It is a phenomenon in which the colors gradually change as the angle of view or the angle of illumination changes. This lustrous color effect is made possible by the reflection and refraction of light on a substrate (Figure 1.1). Iridescence can be manifested through many mechanisms, in the present work, it occurs by thin film interference:

Thin film interference is an optical phenomenon in which light waves reflected by the upper and lower boundaries of a thin film interfere with one another, either enhancing or reducing the reflected light. As exemplified in the following scheme, the incident ray 1 is partly reflected to give ray 2 and partly transmitted and reflected from the bottom surface to give ray 3. The remaining part of the ray is transmitted out of the film to the glass as ray 4. Interference between rays 2 and 3 is possible due to the path difference introduced in the reflection (Tilley, 2011):

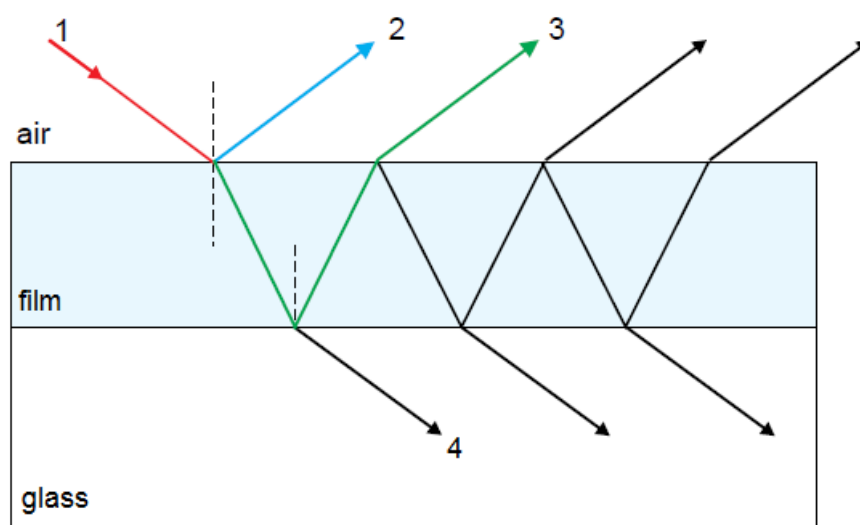


Figure 3.1: Light incidence (1), reflection (2 and 3) and transmission (4) at a thin film on a substrate, here represented by glass (adapted from Tilley, 2011).

The refractive index of the air is different from the refractive index of the film, being this one very thin, in the order of magnitude of the visible light wavelength. The rays represented in the image have different paths when they reach the surfaces, causing the abovementioned interference and consequently different colors depending on the observation angle (Pires de Matos et al., 2017).

The colors revealed by thin film interference on a substrate will depend very much on the films attributes such as thickness, structure and the layers of the film. Therefore those facts will determine the wavelengths to be canceled and the ones to be combined. Finally, depending of all those features, they can range from 400 to 700 nanometers - the entire visible spectrum of light:

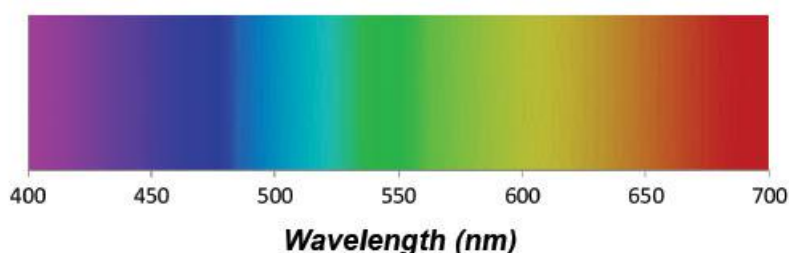


Figure 3.2. Electromagnetic spectrum - the visible light spectrum exemplifies the possible colors viewed at thin films.

Iridescence can be obtained by applying very thin layers of different materials to a surface, but an electrochemical method can also be used to obtain this effect.

3.2 Electrochemistry

Electrochemistry is a science that studies the mutual transformation of chemical and electrical energy inside the structure of electrochemical cells (Bagotsky, 2006). It exists galvanic cells where electric current is produced by a spontaneous chemical reaction within the cell, but there are also electrolytic cell, which are the ones that are explored in this work.

3.2.1 Electrolytic Cells

An electrolytic cell is an electrochemical device that drives a non-spontaneous redox reaction (reduction - oxidation reactions are complimentary electron transfer processes) by the application of an electrical current. (Schüring, 1999).

In these cells, electrons are transferred between the electrodes, those being the anode - positive pole where loss of electrons or oxidation occurs - and cathode - negative pole where gain of electrons, therefore reduction occurs - causing the oxidation state of the ions to change.

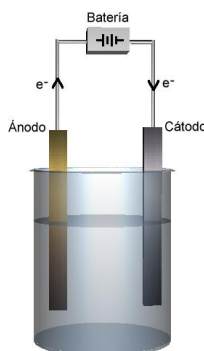


Figure 3.3: Schematic of an aqueous electrolytic cell. The battery provides the potential difference to the system, causing the transfer of electrons from one material (anode) to another (cathode).

The importance of the introduction above will be highlighted in the experimental design section, as it will be fundamental to understand the anodizing of silver.

3.2.2 Anodizing

Anodizing is an electrochemical process used to obtain or increase an oxide layer on the surface of metal parts using an electrolyte solution and applying an electric voltage (Shakhashiri, 1992). It is a versatile process, being applicable as a pre-treatment as well as a final finish to specific metals. Nevertheless, the anodizing process is multi-stage and requires careful application. Even for decorative purposes, variations in the anodizing itself, in the sealing process and other related processing can all make a significant difference to the final result. Thereafter, three common commercial uses of anodizing are exemplified:

"Anodising is used across a whole range of industries, for many different reasons. It has the ability to transform the soft underlying base material Aluminium, into a hard, wear and corrosion resistant engineering material. Applications do go beyond that of aluminium anodising, and Titanium in particular can have its own set of high performing characteristics further improved by the process. Magnesium on the other hand, although still readily anodised benefits from anodising as a pre-treatment for further coating."

(Manufacturing Network, 2018)

Silver, as will be seen in the present work, can also be anodized. With a low voltage applied, it grows a thin transparent layer that can create iridescent colors by thin film interference. (Nurd Rage, 2009)

As anodizing leaves a porous surface on the metals, it is necessary to use a sealant to obtain the desired properties. In the experiment to be presented, the sealant is also very important in order to stop the oxidation process (Manufacturing Network, 2018).

4. How Iridescence Is Produced On Glass

Iridescence on glass has been studied for a long time, since the first archeological discoveries started to reveal corroded pieces of Ancient glass. Iridescent glasses from different chronological periods (for instance from the Roman period) were found in several regions, such as Syria and Cyprus, that after centuries of being buried in the ground began to deteriorate by chemical reaction with the environment. In specific conditions, such pieces presented a beautiful iridized surface caused by a thin degradation layer, called "weathering" - the leaching of alkali from the glass by water, leaving behind siliceous weathering products that are often laminar, with composition different from that of the bulk glass. The iridescence is then caused by the different interaction that light has with these layers of distinct composition (Navarro, 2003).



Figure 4.1: Double balsamarium. 4th to 5th century AD. The Allaire Collection.



Figure 4.2: Perfume Bottle. 1st century AD. The Cesnola Collection.



Figure 4.3: Pourer flask. Early 3rd century AD. Roman, Cypriot. The Cesnola Collection.

As the popularity of this physical weathering effect grew, it began to be copied as a decorative technique by glassmakers around the world, such as Llobmeyer in Vienna (Langhamer, 2003), Thomas Webb in England, Louis Comfort Tiffany and Frederic Carder from Steuben Glass in the USA and by the Austrian firm Loetz (Freeman, 1956). Those glassmakers were recognized as glass artists and their work recognized as "art glass" (Figures 4.4 and 4.5), given the originality and exclusivity of the fine pieces they produced (Arwas, 1997).

At first the induced iridescent surfaces mimicked the ancient glass but further in time, the companies developed brighter and original effects, and by the turn of the 20th century the glasses could be extraordinarily brilliant in color (The Corning Museum of Glass, 2008).

Carnival Glass⁴, a doped and press molded ware that, because of its industrial manufacture was inexpensive, adorned the home of the "working class". It was even casually called "poor man's Tiffany", even if the only real aesthetic similarity between both styles was the iridescence itself. On the other hand, the previously mentioned "art glass" ware, very expensive hand blown glass, included shimmering pieces which decorated the houses of the rich (Thistlewood, 2008).



Figure 4.4: Loetz vase in the Pink Diaspora style. 1902.



Figure 4.5: Cypriote Vase, Favrite Glass. Tiffany Glass Studios.

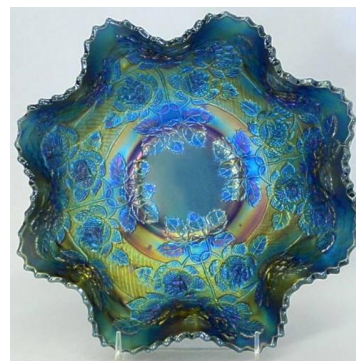


Figure 4.6: Rose Tree Bowl. Blue Glass. Fenton Art Glass.



Figure 4.7: Pulled Husk Corn Vase. Northwood Glass Company.

Below listed there are three traditional techniques used to produce iridescence according to the "Dictionary Of Glass" by Charles Bray (Bray, 2001).

1. The use of a reducing flame to affect metallic materials in the glass:

This method consisted of introducing metallic compounds in the glass batch, later exposing the made pieces to a reducing flame in the glory hole before annealing.

⁴ The term "Carnival Glass" is relatively recent. It was named after the carnival and county fairs through the United States and England in which the glassware was given as prize, after a loss of its popularity (Thistlewood, 2008).

2. Fuming (or spraying):

Fuming was carried out in many factories by placing a metal container near the furnace with stannous or silver salts and then dropping a glob of hot glass into it. The glass piece being worked was then held on top in the emerging fumes until the desired amount of iridescence was achieved.

Nowadays, the common method adapted from the fuming is to mix the salts to be used with distilled water or alcohol and then to spray it onto the glass. For health and safety reasons it is fundamental that this application is carried out directly under a strong exhaust to ensure that the fumes do not harm the operator.

3. The application of lusters:

Traditionally, lusters were made by simmering metallic salts in natural resin for considerable time somewhere in the furnace when the supply of constant heat would be available. The result would be mixed with a suitable medium such as an aromatic oil and when required, thinned with turpentine. Today they are made by specialized suppliers: metallic salts, mostly chlorates are added to a resinate which together with the oil medium provides a built-in reducing agent as it burns out during firing. The material is applied with a soft brush on the cold glass piece. In the early stages of the firing the kiln plugs should be left out to allow some ventilation, however closed studios where the resulting fumes would be discharged, collected and inhaled are not the ideal spaces as most of the bottled lusters are toxic to some extent.

In order to better understand the evolution of the second technique mentioned, the fuming technique used in a factory, I contacted George Fenton, the latter president of the Fenton Art Glass Company, a North American enterprise that made history by being one of the great manufacturers of carnival glass. Fenton was kind enough to describe the different processes used over time:

" The original spraying materials were iron chloride and tin chloride solutions. Both of these are quite caustic and required rubber gloves, face shields and aprons. We would spray into a spray booth which was exhausted to a filter system to avoid exposure to the spray fumes. The spray guns would need to be cleaned frequently and would not last long. These two materials, separately or in combination, are necessary to get the marigold and the stretch finishes. The other material that we used was a titanium material and this was much less corrosive and easier to achieve a basic, shiny carnival look. We would wear the same protective equipment and spray into the same type of booth to deal with the fumes. It had a low flash point so it was kept in insulated plastic containers. We have used three different titanium solutions but stopped one when we found it might cause cancer and stopped the second due to it being ozone depleting. The third was just a basic form of titanium and it worked just the same without the other risks."

(Fenton, 2018)

Anyhow, the demanded studio configuration needed to reproduce the third method disclosed by Fenton, was not what we had in Vicarte's hot shop nor what I intended to perform. Given my desires

for a healthier and environmentally friendlier method coupled with my desire to create an easily accessible production process, a new method was needed.

After rejecting all prior processes, knowing that none of them would work to produce an environmentally friendlier iridescence on glass, we came up with something more sustainable and innovative in glass decoration to the best of our knowledge. Crossing disciplines, I adapted the anodizing process which is a technique for metals to a method for glass silver mirrors, which will be demonstrated in the next chapter.

5. Creative Process and The Experimental Design

5.1 The Magic of Discovery: Interdisciplinarity and The Challenges of Glass

This work moves between concepts that are essentially different, but its results were only made possible by the intersections created in those contrasting directions. Indeed, this work is about experimenting to get iridescent surfaces, but also experimenting with design forms on which to apply these surfaces and finally and most importantly, about analyzing my process of discovery.

The demands of investigation in both art and science, brought about by the research unit, naturally pushed me into a new way of working. This place in which stimuli comes from divergent areas of knowledge had a great tendency to influence my thinking.

The results of my process of discovery in artistic practice led me to questions about how we learn and the words from the educator and author Ken Robinson seemed to translate what I have experienced:

"Creativity also involves making critical judgments about whether what you're working on is any good, be it a theorem, a design, or a poem. Creative work often passes through typical phases. Sometimes what you end up with is not what you had in mind when you started. It's a dynamic process that often involves making new connections, crossing disciplines and using metaphors and analogies." (Robinson, 2015)

Accepting and committing myself to an interdisciplinary investigation affected me deeply. I was given both physical tools and a contemplative space in which to develop my ideas and such fluid circumstances were new to my personal experience. How was that different? I was not concerned with measuring the thickness of my mirror surface, there was an endless number of questions that I could be asking, but I chose this.

I believe the thing that matters most in scientific research or art for that matter is the extent to which creativity leads you. It is not the instrumental analysis that should be considered imperative, but the distance that one has traveled, the amount of discovery, the creativity. For me, it is about discovery.

I had a problem and I am on my way to solve it.

The thing that leads one to the moment of discovery is not quantitative data, it is something that is more subjective. Something less easy to define.

I'm not going to elevate the field of scientific investigation into anodizing silver for now as this work is the first step to a better controlled investigation in the future. Different experimental work is going to be made, however a new process of decorating glass was here created. The field of glass decoration was elevated and in the context of glass art making and design, something new was made. That discovery is much more important to me than any sort of quantitative analysis that I attempt with the results of my process. At least that is how I feel as a designer and artist.

The data that is of most use at this point is me generating some introspection on this so that I can say with some objectivity if the particular process, my experimental design, is in fact part of what got me there, or the main part of what got me there.

I had the time and the space to do something.

That set environment was the driving force as it "shook my head" and took me out of a common place within my own creative scenario. Doing two things at once generated comparisons between them: if I had a given result by anodizing a silver mirror, could it be then enhanced or could it have another effect relating to the glass form? By the texture? By the porosity? And further, could the toning change if masks on the mirror surface were created? So those correlations in fact doubled my personal challenge, as they kept on adding tasks to my exploration in the will to find new results.

I must also say that glass, being a material with its own particularities, helped me dig deeper into the forms and technology that led me to newer results. Because of its technical challenges, it is unlike any other material. During the first months of practice for the present work, I made a number of different blowing moulds trying to create hollow (lightweight) necklace parts with long, narrow and textured shapes (Figure 8.3). They were blown into in many ways: while they were hot (Figure 8.1), while cold, having them dry or wet (Figure 8.2), using the torch and hot shop blowing techniques; all those attempts were discarded and the piece was cast in the end, diverging from my original idea. This is just one example on how glass can be inflexible sometimes and you just might find that you should use another technique (or keep on trying!).

Glass is so hard to master, but that helps us concentrate. It is a material with which one has to be fully engaged. Because you can't touch it, it is always moving, if it cools down too fast it breaks from thermal shock, it has its limitations and we have to work with them. This also helped me find other ways with which I could make something interesting without mastering the material. Its technical difficulties require very long periods of time to develop a real skill set and one also needs to define some achievable goals.

Because of all the technical challenges of this material, I was forced to think in a different way about problem solving. Glass might just be the perfect material for helping a person develop skills in problem solving. You have to reevaluate what's possible, naturally engaging in a different creative process. I changed the way I think about things and that fact has led me into a pursuit of deeper forms of artistic expression. In this work presenting wearable art, that pursuit is still in development.

5.2 Researching the Forms

My first thoughts on wearable glass pieces were related to three areas of the human body: the top of the ear, the neck and shoulder and to the back of the hand. After a rough sketch, I curiously realized that maybe unconsciously I have chosen those areas as they gave me a feeling of support once

covered or "embraced" by the touch of my hand. Maybe that feeling inhabited my mind as a remedy to the path followed to express myself through art, a solitary one.

While exploring the forms, I have found a final shape for the neck and shoulder piece. The other glass pieces are still being explored.



Figure 5.1: Ear piece sculpted in clay, on top of plaster silica model.



Figure 5.2: Attempt in search for deeper texture. Hand cut bubbles from bubble wrap, glued on clay.



Figure 5.3: Resulting cast sample. Too heavy. It also didn't melt enough.



Figure 5.4: Window glass previously slumped on a plaster-silica and bandage mould, built on the body.



Figure 5.5: Same piece after reduction by the saw.



Figure 5.6: Final shape defined.



Figure 5.7: Study for a hand piece in development.

5.3 Innovative Process of Anodizing for Iridescent Decorative Surfaces on Glass

Narrowing my research to anodizing or electronic oxidation of metals, while collecting data, I found an experiment recorded on video (Nurd Rage, 2009) which helped me see how I could anodize a solid silver bar if it was immersed in a chemical salt solution with an electric potential applied to it. This anodizing process could result in multiple iridescent colors, by the effect of thin film interference aforesaid.

Right after watching such video I asked myself: could it also be induced in a silver mirror deposited onto glass? Did the silver film have enough thickness for that purpose or would it be completely black?

5.3.1 The Silver Mirror Deposition

Preparation

For the mirror deposition, a protocol from the literature was used (Shakhashiri, 1992). Different solutions were prepared: 300 mL of 0.1 M silver nitrate (AgNO_3), 150 mL of 0.8 M potassium hydroxide (KOH) and 100ml of 0.5 M of glucose ($\text{C}_6\text{H}_{12}\text{O}_6$).

Previous to performing the silver mirror deposition on glass, it is imperative to have a thoroughly cleaned glass surface. Therefore, the samples should be dipped in nitric acid and in potassium hydroxide for removing the metallic impurities and the grease which could affect the silver deposition. For safety reasons this experiment must be done in a well ventilated space, preferably under a fume hood. The entire preparation has to be finished in less than a couple of hours or else the solution would generate a highly poisonous and explosive chemical called silver nitride (Shakhashiri, 1992).

Experiment

While being stirred using a magnetic bar, potassium hydroxide is added slowly but continually to the silver nitrate in the beaker, which will form a dense precipitate of silver oxide (Figure 5.8, reaction 1). Afterwards, a few drops of ammonia are added to form a complex, the precipitate will disappear slowly until the solution is fully clear (reaction 2). At this point, the glass pieces are carefully added to the solution (Figure 5.9). Thus, glucose is added to the solution to reduce the silver oxide to metallic silver (reaction 3) which will deposit after some minutes on the sample's surface as well as to the beaker walls (Figure 5.10).

In Figure 5.11 it is possible to observe the glass samples mirrored and washed with distilled water.



Figure 5.8: The silver precipitate is formed by silver nitrate and potassium hydroxide.

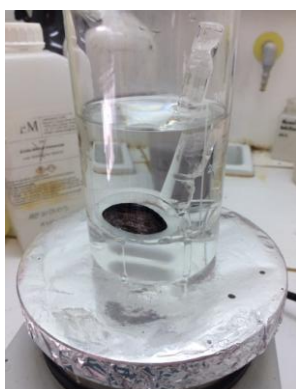


Figure 5.9: After the addition of ammonia, the solution turns clear.

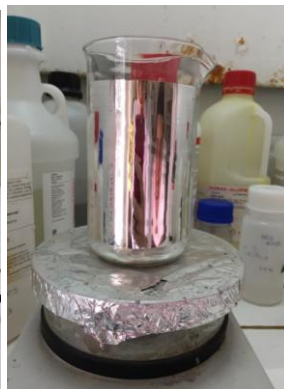
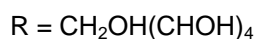
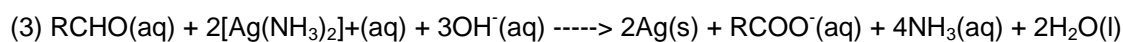
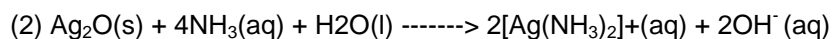
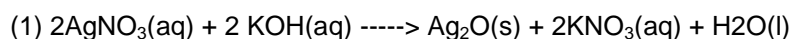


Figure 5.10: The silver oxide is reduced by glucose to metallic silver.



Figure 5.11: The samples are mirrored.

Reactions



5.3.2 The Anodizing Solution

To proceed with the silver mirror anodizing a solution has to be prepared.

Preparation

Right after the mirrors are ready and rinsed with distilled water it's time to prepare the anodizing solution that will oxidize the silver layer and reveal the desired iridescence. For that solution, it was used 200 mL of 3.75 M sodium hydroxide (NaOH) and 3 g of sulfur (S). Once mixed, those compounds can result in a hydrate of sodium sulfate. Sodium hydroxide is corrosive, therefore gloves and safety glasses are needed when handling it.

Experiment

Sulfur is slowly added to the NaOH solution under agitation as the liquid turns light yellow (Figure 5.12), but the desired resulting solution should be bright in color, tending to orange (Figure 5.14). We let it be continually heated and stirred for as long as it needs.

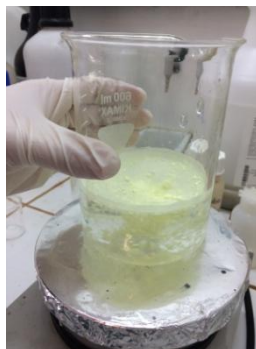


Figure 5.12.: Sulfur is added to the sodium hydroxide solution.



Figure 5.13: The compound needs a lot of stirring under heat, as sulfur has a low solubility.

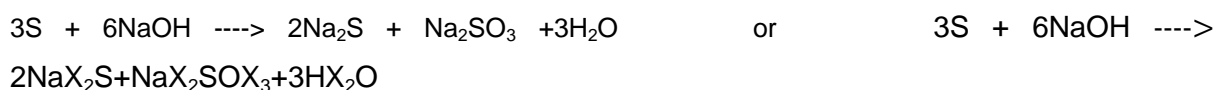


Figure 5.14: After reaching an orange color the solution should be filtered.



Figure 5.15: Removing the excess sulfur, it is ready to anodize the silver mirrors.

After one hour and twenty minutes the solution had a strong color and it could then be filtered to remove the excess of undiluted sulfur. Depending on the reaction conditions, different sulfur compounds can be obtained. In the literature, the following reactions were found:



The solution is poured to a glass container. A sample is placed inside the container and immersed in the solution. Using a 1.5 V battery connected to copper wires at each pole we create the electric potential to move the electrons from our cathode, the H_2O of the solution, to our anode, the Ag^0 layer deposited on the glass sample. So we connect the positive wire to the glass silver layer and place the negative wire on the solution. Rapidly, oxygen bubbles will be released near the cathode, where the copper wire is in contact with water while the reaction occurs, oxidizing the silver and reducing the water (Figure 5.16). What is happening is at the cathode we are generating hydrogen gas, but at the anode we are oxidizing the silver and probably combining it with sulfide ions to make silver sulfide which is the tarnish we see on the silver (Araújo et al., 2018). The final color is dependent on the voltage and on how long (3 V and 1.5 V) the voltage is applied defining the thickness of the silver sulfide layer. Therefore different voltages and times were applied until parameters were defined in

order to obtain a control pattern. Finally the 1.5 V battery was used to anodize five samples, respectively for 1.5 s, 2.95 s, 5 s, 5 s and 6.06 seconds.

The scheme illustrates the components and the reactions of the particular anodizing process:

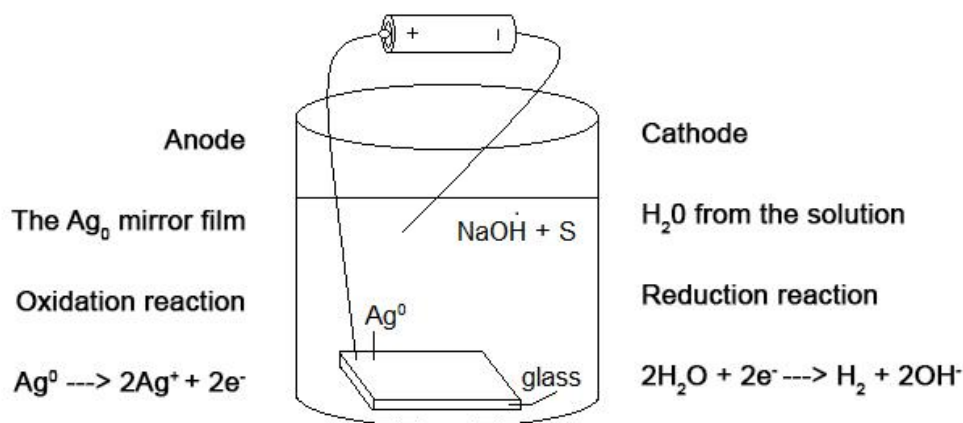


Figure 5.16: The electrolytic cell configuration and the respective chemical reactions for the anodizing.

This process allows for a more sustainable application of the iridescence on glass pieces if compared to the traditional methods, once there is no volatilization of toxic elements during the film formation. It is also a process of easy application which can be reproduced in any studio.

Another advantage is that by this particular method, the glass piece to be anodized is already made, opposite to the traditional techniques, where the glass is hot while still being worked or has to be heated in order to obtain the iridized surface.

6. Results and Discussion: Iridescent Samples Produced

6.1 Different Voltages

For our first experiments, we used two batteries attached, putting together 3V of potential to the cell. This voltage was the one used by Nerd Rage, which inspired my adaptation. Although, as a film of metallic silver is a lot less substantial than a solid silver bar, the tarnishing happened too fast and it was hard to control the time of exposition to the electric potential, as we see on figures 6.1 and 6.2. The samples became very dark extremely fast and the desired effect was not obtained.



Figure 6.1: Two of the first samples. Borosilicate rod and pate de verre nutshell. Anodized under potential of 3 V. during 1.5 s and illuminated by a natural light source.



Figure 6.2: Both samples previously mentioned and a sodalime glass piece cut by the diamond saw. Illuminated by a white light source.

For that reason we decided to try one battery of 1.5 V for the next experiments in order to have controllable results. Consequently, the oxidation velocity was reduced.

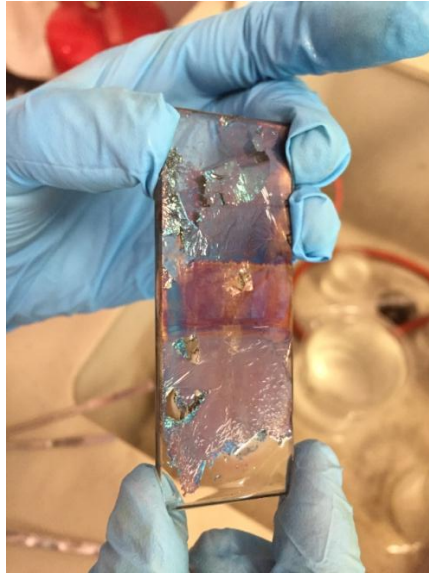


Figure 6.3: One of the first samples anodized with 1.5 V.

6.2 Different Times

The voltage of 1.5 V was applied to the silver mirrored samples during different times in order to obtain a variation of colors.



Figure 6.4: After anodizing we see a great variation of colors (seen from above). Voltage 1.5 V applied for 1.2 s, 2.95 s, 5 s, 5 s and 6.06 s.

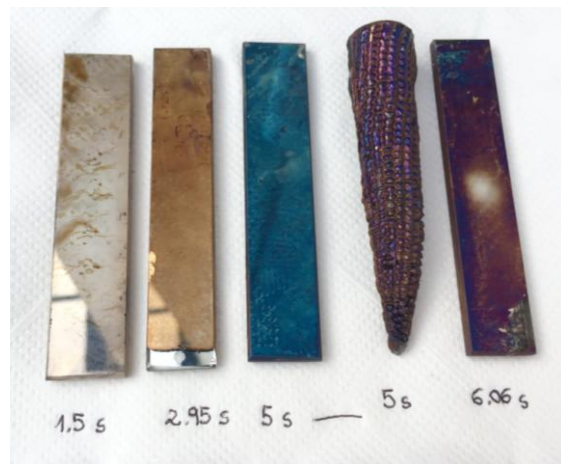


Figure 6.5: The samples are now flipped and different colors are noticed, seen from above.

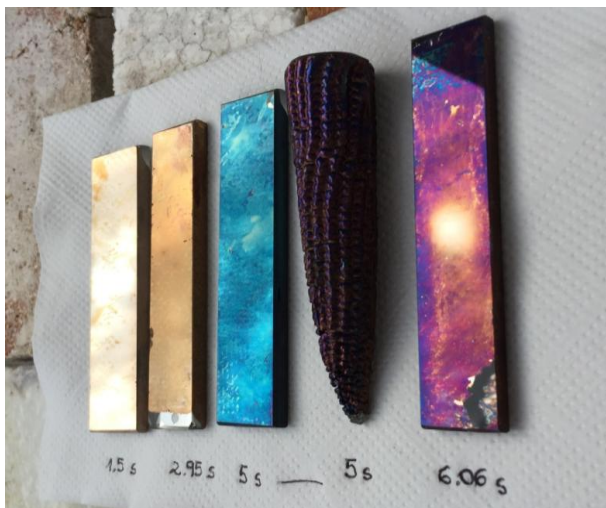


Figure 6.6: The colored mirrors reflection under the sunlight and observed by another angle.



Figure 6.7: A close up shows a diverse array of colors. Respectively, 2.95 and 6.06 s.

In order to verify the colors seen by naked eye, diffuse reflectance measurements were performed in a Avantes AvaSpec-2048 spectrometer. As the samples are not completely homogeneous and are iridescent, different reflectance spectra could also be obtained. Furthermore, colorimetry can also be made.

All samples were analyzed under the abovementioned equipment and small differences can be observed. In the 1.5 s and 2.95 s samples, the percentage of reflectance is higher than the 5 s and 6.06 s samples that showed lower reflectance (Figure 6.8).

Comparing the reflectance spectra of samples 5s and 6.06 s, where the iridescence effect seems stronger we can observe some differences. Sample 5 s, which has tones of pink, purple and blue represented as the dominant colors, reflected light from 400 to 500 nm, corresponding to the blue color, and also from 600 to 700 nm which corresponds to colors from yellow to red. This sample shows similarities with the "6.06 s" one, which also reflects from pink to blue but has less reflection on the blue area as we can see with our eyes. To do a more adequate optical analyses of the iridescent samples it is necessary to measure the angle-dependent reflected (or more generally scattered) light intensity. (Fu, 2017)

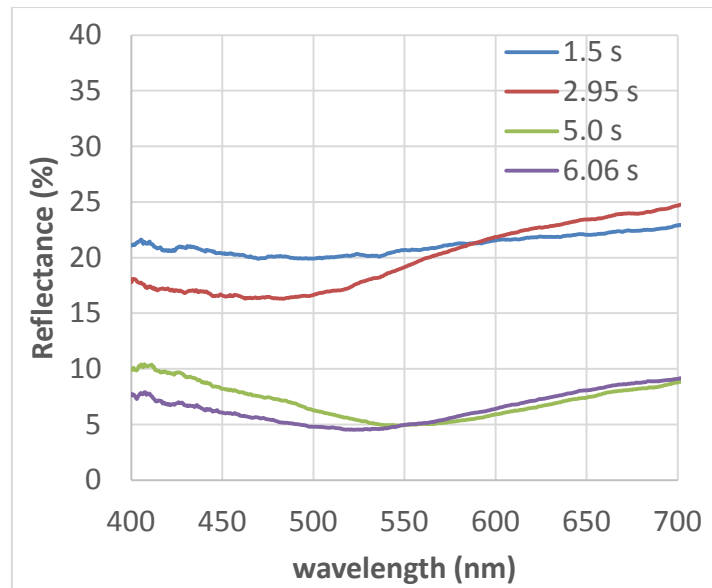


Figure 6.8: Reflectance spectra of float glass anodized samples during different times.

6.3 Sealing

The pictures presented for the timed samples were all taken on the same day of the tarnishing procedure. Silver oxidation can still continue after the experiment, therefore it takes a few hours until the anodized layer settles on the final colors. In order to stop that, I had a spray varnish on hand, with which the anodized silver layer could be protected, stopping its interaction with the air. The pieces were thoroughly sprayed two times each, with approximately 2 hours apart. But after setting the glasses aside for some days, they turned darker. I believe it happened because my varnish was for paintings, anyhow inappropriate for a coating on glass. The used spray is not a good sealer, probably because the used varnish has a high porosity. My second attempt was to dip coat two samples in an epoxy resin diluted with alcohol with the hope to make the film colors stable and durable. It worked quite well for that purpose and it turned the surface shiny, which was an interesting effect. But air bubbles from the mixing were formed and stayed in the dry resin coat and excess resin didn't run from the sample entirely, leaving a kind of "resin pocket".



Figure 6.9: Partially dip coated samples.

For a future attempt the epoxy resin, mixed with drops of alcohol, will be left to rest prior to be delicately deposited on top of the anodized surface with a soft brush. Maybe then, I will obtain a smooth protecting surface without bubbles. Controlled heat can also be used for releasing occasional air bubbles (Koob, 2006).

6.4 Analyzing the Anodized Layer

Aiming to confirm the composition of the anodized silver layer on the glass piece after this process, we found in the literature that probably silver sulfide is the responsible for the silver tarnishing, as that fact is accepted by the cultural heritage field. Nevertheless, it doesn't characterize the essential mechanism, as silver does not react directly with sulfide, even in the presence of high sulfide concentrations. The first step to the oxidation process initiates with the absorption of oxygen on the surface of silver (Araújo et al., 2018).

However, as silver sulfide (Ag_2S) has a lower constant of solubility (K_{sp}) than silver oxide (Ag_2O), it dilutes less in the solution, therefore Ag_2S precipitates more on our silver film, defining our final layer product (Lyu et al., 2013), as seen in the reaction added to our anodizing scheme:

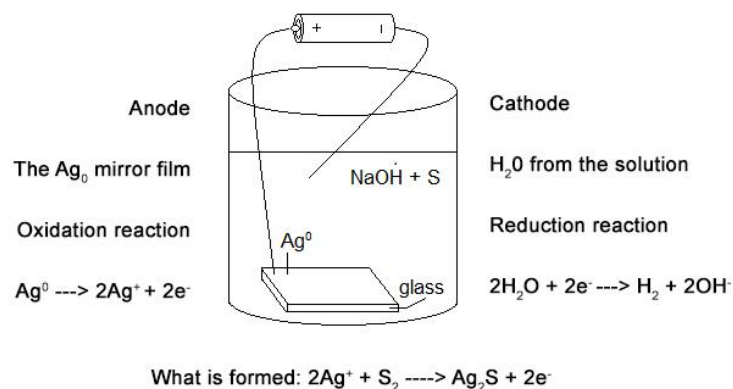


Figure 6.10: The formation of the definitive degradation product from the tarnishing of silver is represented in the anodizing scheme.

For verification, we analyzed the samples by Raman Spectroscopy⁵ as seen in figure 6.11. In the spectroscopy, a Jobin Yvon-Labram 300 spectrometer was used, a 532 nm laser, a 50x objective and a power of 0.35 mW. The following spectra (Figure 6.11) confirms the presence of Ag_2S (Martina et al., 2012). Around 1467 cm^{-1} we can observe a peak that corresponds to Ag_2S degradation due to The Raman laser (Martina et al., 2012).

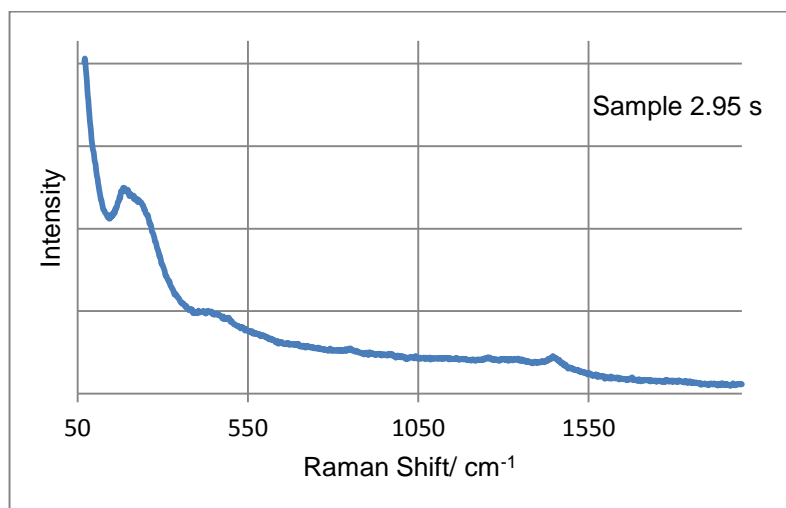


Figure 6.11: Raman spectrum of the 2.95 s sample.

⁵ The Raman Spectroscopy registers the vibrations between chemical bonds, in this case between silver and the sulfide. Therefore, from the spectrum recorded by the equipment, we can identify the exact product deposited on the glass, comparing it to the related literature.

7. Final Piece: Suporte Cintilante









Figures 7.1, 7.2, 7.3 and 7.4: As I move with the art piece, its shades change and reveal a beautiful array of colors.

8. Conclusions

How gratifying it is to realize that a persistent interaction with material combined with my most personal ideas could bring new things to life. Throughout my path to discovery, my experimental design itself, developed in between art and science, had great parcel of the solution to my problem, even before I knew it. Yet, I was encouraged by inspiring minds, be them physical or virtual, by the knowledge that is all around us far and wide our daily lives.

After having experienced the benefits of interdisciplinary practice throughout this research, I could develop a sustainable approach to iridescence in glass decoration by anodizing glass silver mirrors. Having adapted such traditional glass finish, first revealed by the earth to our astonished eyes and so well played by great masters of glass history is just a good start to exhaustive practice.

In order for that technique to be carried out in the future, the ideal sealing method has to be investigated to ensure a stable and durable surface. Moreover, aging tests or simply time alone will say if those surfaces can be applied to everyday jewelry pieces. Another interesting conclusion is that the colors obtained by the anodizing highly depend on the position and distance of the electrodes to the mirror, which adds to the design possibilities.

About future glass jewelry designs to be developed for applying such technique, research on production costs and related viability should be made, so to create a commercial line that is accessible, moneywise, just as in between carnival glass and art glass from the early 20th century.

At present, to receive the iridized finish, one wearable art piece was created and others are still being developed to complete a body of work that is in tune with my personal contemporary jewelry practice. Such practice is fundamental to me as a creator as it relates to art practice alone, therefore to liberty.

The final conceptual piece presented is understood as a first step into a direction where I aim to develop creativity through art, afar from product driven design. Such strategy can function as a tool to improve my professional design practice.

Besides all the aspects that made this research "worth the dive", the greatest one was overcoming the difficulties of glass technique by changing my focus and using the material as an artistic vehicle. Once I accepted that, I started to develop skills in problem solving, which has certainly changed the way I think about everything inside the wide spectrum from science to art.

The results of this thesis present a strong potential for further improvement and exploration that will continue to feed my creative inquests.

9. Annex



Figura 8.1: A hot mould cracked after blowing attempts.



Figure 8.2: A wet blown mould after being soaked in water.



Figure 8.3: A baby corn inside its mould.



Figure 8.4: Some attempts of blown glass corns which didn't reach the whole mould length.



Figure 8.5: A completely blown corn, although too thin.



Figures 8.6, 8.7 and 8.8: Samples masked with hot glue (after the mirror deposition) were anodized and the mask was pulled off.

Figure 8.8: Samples coated with spray varnish. The application was wrong, showing an uneven coat.



Figures 8.9, 8.10 and 8.11: Other possible effects obtained by the anodizing technique, such as an induced capillary action from the solution to the mirror that is not dipped (8.11) or double anodizing with different mirror sections dipped (8.10).

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